International Journal of Research
Available at
https://edupediapublications.org/journals

p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 04 Issue 13
October 2017

Inverse Kinematic Analysis of Lab-Volt R5150 Robot system

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ABSTRACT

Kinematics analysis is the conversion from the Cartesian space to the joint space and vice versa. In this paper, an inverse kinematics modeling of 5 DOF stationary articulated robot arm which is used for educational tasks are presented, and shows an adopted modeling method to simulate and represent the simultaneous positional coordinates for each joint of the robot while it moving from one target to another. The standard Denavit-Hartenberg (DH) model is applied to build the mathematical modeling to determine and simulate the position and orientation of the end effector of (5 DOF) Lab-Volt R5150 robot manipulator. The simulation of the inverse kinematic of the robot arm is done through MATLAB software and compare the results with the data from RoboCIM software to know that the model is suitable for simulate and represent.

Keywords *- Lab-Volt R5150 robot arm, D-H parameters, DOF, Inverse Kinematics.*

1. INTRODUCTION

The inverse kinematics solution, it is essential for robots that follow paths. A computer control system called the controller, commands the robot to move through its workspace based on a plan or desired trajectory of the robot end- effector. The plan is developed using an inverse kinematics algorithm which computes the next desired joint configuration given the current configuration and the next desired end effector position [1].

Inverse kinematics deals with the problem of finding the required joint angles to produce a certain desired position and orientation of the end-effector. The inverse kinematics problem is much more complex than direct kinematics, because the kinematic equations are nonlinear, their solution is not always easy (or even possible) in a closed form. Also, questions about the existence of a solution and about multiple solutions arise [2] [3].

Inverse kinematics will calculate what each joint variable must be if the desired position and orientation of end-effector is determined. Inverse kinematics is defined as transformation from Cartesian space to joint space. In general, the inverse kinematics problem can be solved either by an algebraic, an iterative, or geometric approach. The closed form solutions are preferable for two reasons. The first, the forward kinematics equations must be solved at a rapid rate and the second, kinematics equations in general have multiple solutions. Inverse Kinematics analysis determines the joint angles for desired position and orientation in Cartesian

p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 04 Issue 13
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space. This is more difficult problem than forward kinematics [4].

2. Description of Lab-Volt R5150 Robot Arm

For this study, Lab-volt R5150 robot manipulator was selected in this research, as shown in figure (1). It is an educational robot from the family of Lab Volt Automation. It is a small table top robotic arm manufactured by Lab-Volt Inc. It is a 5 DOF manipulator driven by five stepper motors and has a griper as an end-effector, and its motion are controlled by RoboCIM, IM Software [5][6].

Fig 1: Lab-Volt R5150 manipulator

Lab-Volt R5150 robot arm has base, shoulder, elbow, tool pitch and tool roll, which are all consisting rotary joints and provide 5 directions of motion (DOF) plus a grip movement. The first joint is the Base which provide rotational motion θ1 around z0 axis in (x0, y0) plane. The second joint represents the shoulder which its axis perpendicular to joint 1 axis and provide an angular motion θ2 in (x1, y1) plane. The axis of motion for third (elbow) and fourth (wrist) joints is parallel to the z-axis of joint 1. These joints provide the angular motion θ3 in (x2, y2) plane and θ4 in (x3, y3) plane respectively. The last joint is identified as the gripper and its axis of motion is vertical to z3. It is provide angular motion θ5 in (x4, y4) plane as shown in Figure (2).

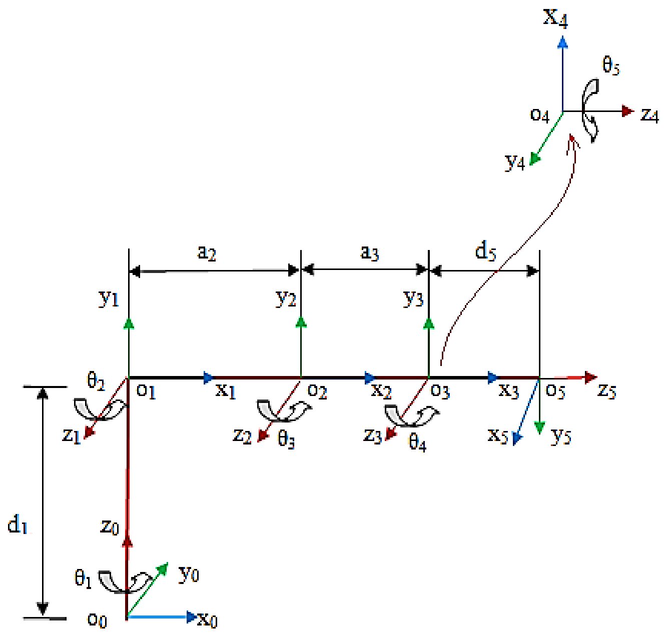


Fig 2: Coordinate frames for Lab-Volt 5150 manipulator.

3. Kinematic Analysis of Lab-Volt R5150 Robotic Arm

3.1 Forward Kinematic

In the forward kinematics, the inputs are the joint angles and the link length parameters, while the output of the problem is the position and the orientation of the tool or gripper. The block diagram representation of the direct kinematics shown by Figure (3).

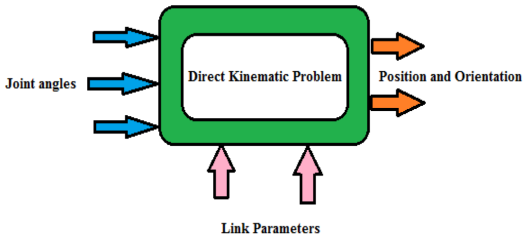


Fig 3: Direct Kinematic Block Diagram.

Many methods can be used in the forward kinematics estimation. One of the most used methods is the Denavit-Hartenberg (D-H) analysis, in this method the forward kinematics is calculated from some parameters that have to be defined to produce homogeneous transformation matrix [1]. This matrix specified the position and orientation of the robot arm with respect to the robot base. In Denavit-Hartenberg (DH) convention, each homogeneous transformation is represented as a product of four "basic" transformations:

$$A_i = Rot_{z,\theta i}\ Trans_{z,di}\ Trans_{x,ai}\ Rot_{x,\alpha i}$$

$$= \begin{bmatrix} c_{\theta_i} & -s_{\theta_i} & 0 & 0 \\ s_{\theta_i} & c_{\theta_i} & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & a3 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & c_{\alpha_i} & -s_{\alpha_i} & 0 \\ 0 & s_{\alpha_i} & c_{\alpha_i} & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} c_{\theta_i} & -s_{\theta_i} c_{\alpha_i} & s_{\theta_i} s_{\alpha_i} & a_i c_{\theta_i} \\ s_{\theta_i} & c_{\theta_i} c_{\alpha_i} & -c_{\theta_i} s_{\alpha_i} & a_i s_{\theta_i} \\ 0 & s_{\alpha_i} & c_{\alpha_i} & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

The D-H parameters from Table (1) will be substituted at equation (1). The individual transformation matrices A_1 to A_5 and the global matrix of transformation A_5^0, can be calculated as follow:

Table 1: D-H parameters for Lab-Volt 5150 arm

Frame	θ_i	d_i (m)	a_i (m)	α_i (degree)
1	θ_1	255.5	0	90
2	θ_2	0	190	0
3	θ_3	0	190	0
4	θ_4	0	0	90
5	θ_5	115	0	0

p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 04 Issue 13
October 2017

$$=\begin{bmatrix} c_1 & 0 & s_1 & 0 \\ s_1 & 0 & -c_1 & 0 \\ 0 & 1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} c_2 & -s_2 & 0 & a_2c_2 \\ s_2 & c_2 & 0 & a_2s_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} c_3 & -s_3 & 0 & a_3c_3 \\ s_3 & c_3 & 0 & a_3s_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_1^{\,0} \quad , \quad A_2^{\,1} \quad , \quad A_3^{\,2} \quad , \quad A_4^{\,3}$$

$$A_5^{\,4} = \begin{bmatrix} c_5 & -s_5 & 0 & 0 \\ s_5 & c_5 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_5^{\,0} = \begin{bmatrix} c_{12345}+s_{15} & -s_5c_{1234}+s_1c_5 & c_1s_{234} & c_1(d_5s_{234}+a_3c_{23}+a_2c_2) \\ s_1c_{2345}-c_1s_5 & -s_{15}c_{234}-c_{15} & s_1s_{234} & s_1(d_5s_{234}+a_3c_{23}+a_2c_2) \\ c_5s_{234} & s_5s_{234} & -c_{234} & -d_5c_{234}+a_3s_{23}+a_2s_2+d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad \ldots\ldots\ (2)$$

3.2 Inverse kinematic

Inverse kinematics deals with the problem of finding the required joint angles to produce a certain desired position and orientation of the end-effector in Cartesian space. Its solution, however, is much more complex than direct kinematics since there is no unique analytical solution. Each manipulator needs a particular method considering the system structure and restrictions [7].

When the final position and orientation of the end-effector are specified, Inverse kinematic can be obtained by geometric approach with the inputs data (a2, a3, d1, d5):

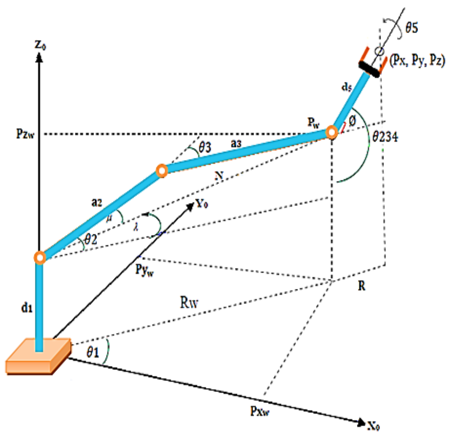


Fig 4: The 4 link articulated robot

From figure (4), the relation between (θ1, θ2 and θ3) is:

$$\phi = \theta_2 + \theta_3 + \theta_4 \quad \text{....... (3)}$$

The joint angles of the articulated robot will be found according to the following steps:

$P_{zw}=P_z+d_5*\sin\phi$ .... (4)

$$R_w = \sqrt{\left(p_x^{\,2} + p_y^{\,2}\right)} - d_5 * \cos\phi \quad \text{....... (5)}$$

$$N = \sqrt{\left((p_{zw} - d_1)^2 + R_w^{\,2}\right)} \quad \text{....... (6)}$$

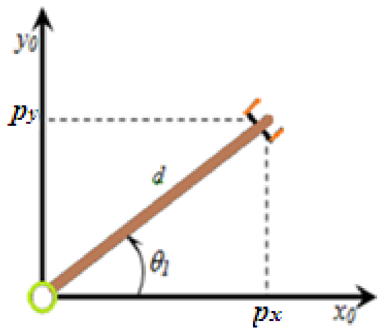


Fig 5: Top View of Robot

Step 1: Solution for θ_1 - from figure (5):

$$\theta_1 = a\tan 2(p_y, p_x) \quad \text{....... (7)}$$

Step 2: Solution for θ_2

By using the law of cosines:

$$\mu = \cos^{-1}\left(\frac{N^2 + a_2^{\,2} - a_3^{\,2}}{2a_2 N}\right) \quad \text{...... (8)}$$

$$\lambda = a\tan 2[(p_{zw} - d_1), R_w] \quad \text{....... (9)}$$

$$\theta_2 = \lambda \mp \mu \quad \text{....... (10)}$$

Step three: Solution for θ_3

$$\theta_3 = \pm\cos^{-1}\left(\frac{N^2 - a_2^{\,2} - a_3^{\,2}}{2a_2 a_3}\right) \quad \text{....... (11)}$$

Step four: Solution for θ_4

$$\theta_4 = \theta_{234} - \theta_2 - \theta_3 \quad \text{....... (12)}$$

Step five: Solution for θ_5

To estimate the value of the angles θ_5, the matrix A_3^{5} should be available:

$$A_5^{3} = \begin{bmatrix} c_{45} & -s_5 c_4 & s_4 & d_5 s_4 \\ s_4 c_5 & -s_{45} & -c_4 & -d_5 c_4 \\ s_5 & c_5 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} n_x & s_x & a_x & p_x \\ n_y & s_y & a_y & p_y \\ n_z & s_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$n_z=s_5$ (13)

$s_z= c_5$ ...... (14)

$$\frac{n_z}{s_z} = \frac{s_5}{c_5} = \tan\theta_5 \rightarrow \theta_5 = \tan^{-1}\left(\frac{n_z}{s_z}\right) \quad \text{.... (15)}$$

4. EXPERIMENTAL WORK:

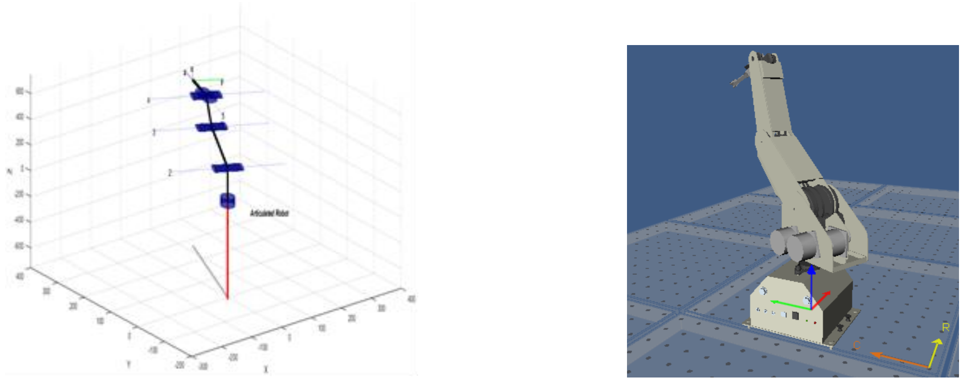
The Forward Kinematic is invested to calculate the final position of the end effecter and work envelope of the articulated robot. The driven inverse Kinematics equations have been investigated for several cases to guide the robot to a predefined position (Px, Py, Pz). The joint angles (θ1, θ2, θ3, θ4, θ5) of the articulated robot have been determined.

To evaluate the proposed procedure, three cases have been performed for the model of Lab-Volt R5150, where the result compared with RoboCIM software. The errors between these cases listed in table (2).

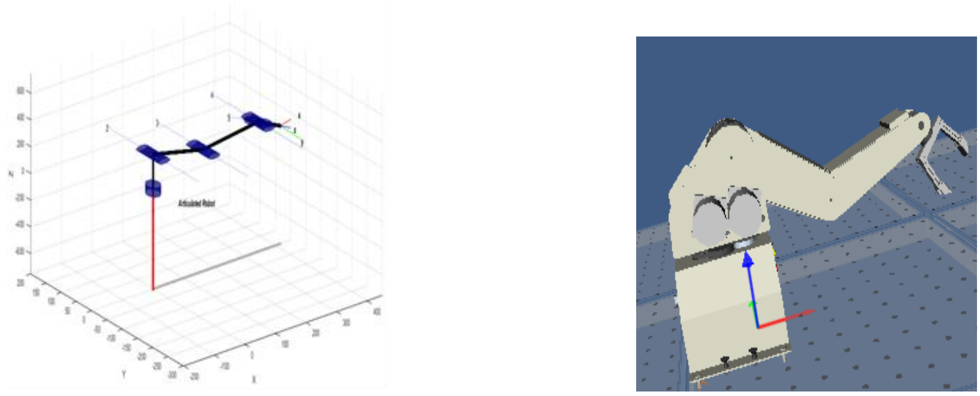
Table 2: Experiment and Simulation results for inverse kinematics of Lab-Volt R5150 robot arm

Cases	End-effector position (True)	Joint variables calculated	End-effector position (Measured)	Error% = $\frac{true - measured}{true} * \%$
1	Px = 121.626 Py = 264.555 Pz = 538.062	θ1 = 65.31 θ2 = 44.15 θ3 = 32.12 θ4 = -3.65 θ5 = 49.99	Px = 121.62 Py = 264.53 Pz = 538.95	0.005% 0.009% 0.165%
2	Px = 416.523 Py = 0 Pz = 131.288	θ1 = 0 θ2 = -30.52 θ3 = 49.3 θ4 = 20.6 θ5 = -19.29	Px = 416.93 Py = 0 Pz = 131.25	0.098 % 0.0 % 0.029 %
3	Px = 362.627 Py = -161.452 Pz = 89.930	θ1 = -24 θ2 = 15.76 θ3 = -60.421 θ4 = 88.011 θ5 = -89.48	Px = 362.94 Py = -161.59 Pz = 89.76	0.086% 0.085% 0.189%

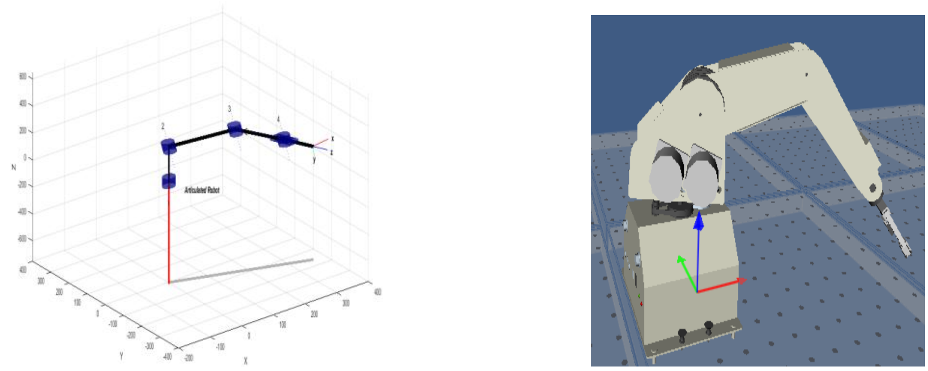
FIGURE (6) ILLUSTRATE THE SIMULATION MODE OF THE LAB-VOLT R5150 ROBOT MANIPULATOR IN MATLAB AND ROBOCIM SOFTWARE:



Case (1)



Case (2)



Case (3)

(a) (b)

Figure (6): a- simulation plot in MATLAB, b- simulation mode in RoboCIM software for the three cases

5. Conclusion

Most industrial applications require access to a known goal, (i.e. the target is known coordinates (Px, Py, Pz), and driving the robot required derivation of inverse kinematic analysis for leading the robot to the specified target. The adopted method in this research and through many experiments proving its efficiency and compliance with the objective assigned to it through matching its dimensions perform tasks smoothly

By adopting inverse kinematic analysis in this work we were able to identify the joints location for each movement of the robot's movements, allowing us to avoid obstacles during the path of the robot. There are two methods to solve inverse kinematic analysis are upper and lower solution and that used through the solution adopted in this research, according to the goal and the way to reach it. From the solution of the selected cases, we can observe that the value produce from upper solution is very close to the testing input than the results from lower solution and the percentage error between the true value and measured result are very close to each other.

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